III.E.1 Hybrid Ceramic/Metallic Recuperator for SOFC Generator

Objectives

- Design and fabricate a three-pass, cross flow heat exchanger utilizing metallic materials for the first and second pass and ceramic material for the high temperature third pass.
- Further develop molds and casting techniques to produce a ceramic monolith with the necessary heat transfer surface.
- Characterize the performance of the hybrid recuperator and evaluate its ability to withstand thermal shock.

Accomplishments

- Contractual details were completed and work on this project was initiated on June 28, 2006.
- Acumentrics' recuperator test stand was upgraded to allow for separate control of the air side and exhaust side gas streams. A new furnace plenum will also permit higher exhaust side recuperator pressure drops to be tested.

Introduction

Solid oxide fuel cells (SOFCs) are one of the most efficient and cleanest power generating systems being developed. SOFCs can operate on presently available fossil fuels and do not require precious metal catalysts which can be prohibitively expensive. SOFCs achieve this, in part, by operating at relatively high temperatures in the range of 800 to 1,000 degrees Celsius. Although these operating temperatures are well within the range of standard ceramic and refractory materials, where metals are required, expensive high alloy materials must be utilized.

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A key component in the SOFC generator is the cathode air heat exchanger or recuperator. The function of the recuperator is to ensure that the cathode air, and thereby the cells, are at sufficient temperature to permit ion mobility, and to improve overall SOFC system efficiency by reducing stack losses. Since the heat capacities of the gases on each side of the recuperator are essentially the same and high heat exchange is essential, the recuperator requires a large heat transfer area. To date metallic recuperators have been utilized and the state-of-the-art metallic recuperator is estimated to cost around \$200/kW assuming volume production. This is a significant portion of the overall generator cost which must be between \$400 and \$1,000/kW to achieve commercial viability. This work is aimed at developing a low-cost recuperator through the use of a combination of low-cost ceramic and metallic materials along with low-cost manufacturing techniques.

Approach

The work to be conducted will focus on the development and demonstration of a "hybrid" recuperator which combines a high temperature ceramic section with a low temperature metallic section to reduce the overall cost of the unit while achieving the high effectivenss and long life required by an SOFC generator. This arrangement will take advantage of the high temperature, low fouling capability of a ceramic heat exchanger core while allowing lower grade metallic materials, with high extended surface area, to be used in medium to low temperature regions. By incorporating the ceramic and metallic sections into a single unit, costly interconnect ducting and fittings along with associated support structure and insulation will not be required, significantly reducing the cost over non-integrated solutions. Figure 1 shows an exploded view of the concept.

Results

Previous to the award of this SBIR grant, Acumentrics (as part of its Solid State Energy Conversion Alliance grant) and Blasch Precision Ceramics, (co-funded by New York State Energy Research and Development Authority) designed, manufactured and tested a three pass, cross flow ceramic monolith recuperator. Although significant strides were made in manufacturing the monolith and establishing simple methods of attaching inlet and outlet plenums, the heat exchange effectiveness of the unit (approximately 67%) was below that required for

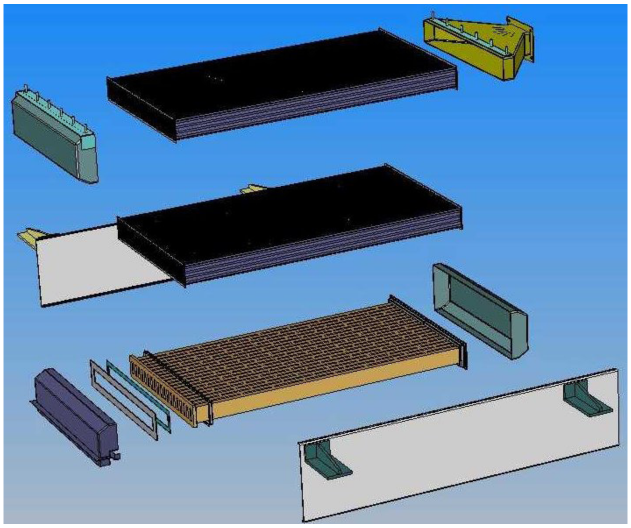

FIGURE 1. Exploded View of the Hybrid Heat Exchanger Concept

FIGURE 2. Three-Pass, Cross Flow Ceramic Monolith

efficient operation of the SOFC generator (>80%). The low effectiveness is in part a result of utilizing a low-cost, "net" shape casting technique which does not require costly machining. The casting technique requires relatively large wall thickness to achieve a structurally sound, leak-free monolith and limits the incorporation of extended surface area (fins). Figure 2 shows an example of the three-pass, cross flow ceramic monolith.

Additionally, Acumentrics has worked with a third party heat exchanger manufacturer in the design and testing of three-pass, cross flow and counter flow metallic recuperators which can meet the SOFC goals but require the use of high alloy materials to withstand the relatively high inlet exhaust temperatures (950°C) and corresponding high air preheat temperature (800°C) of the SOFC application. As shown in Figure 3, the metallic recuperator utilizes a fin core technology. The fin core consists of rectangular tubes with corrugated, fin material within the tubes and sandwiched between tubes.

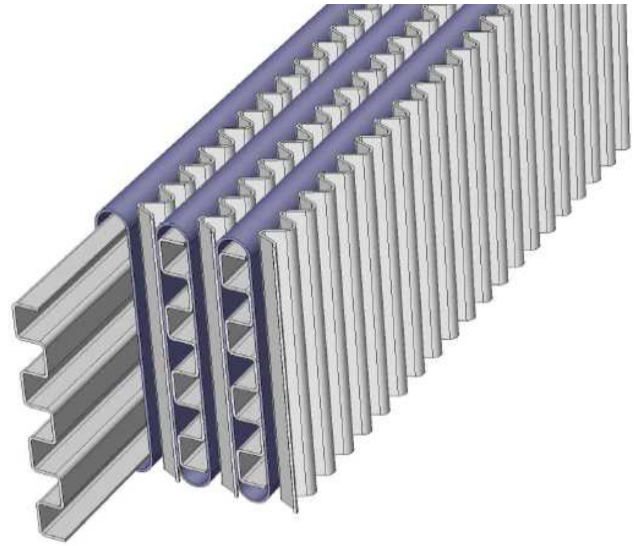

FIGURE 3. Metallic, Fin Core Geometry

Testing of recuperators has been performed in a dedicated recuperator test stand which simulates Acumentrics' SOFC generator geometry as far as the cathode air flow and temperature conditions are concerned. This facility was upgraded to permit separate control of the air side and exhaust side gas streams. A new furnace plenum was also designed and built which will permit testing of recuperators with higher exhaust side pressure drops.

Conclusions and Future Directions

The work to be conducted under this Phase I SBIR grant will prove the technical viability of the "hybrid" cross flow recuperator. The specific Phase I technical objectives are:

1. Perform thermal modeling to determine the required geometries of the individual passes to achieve the desired final and intermediate gas and material temperatures.
2. Define acceptable operating temperatures for candidate tube, fin and plenum materials.
3. Design and test a suitable attachment method to seal and support the ceramic monolith within the recuperator framework.
4. Design and fabricate a mold capable of forming the prototype single pass ceramic monolith.
5. Fabricate ceramic monoliths of oxide bonded silicon carbide and alumina oxide.
6. Determine the heat exchange characteristics of the individual ceramic and metallic sections.
7. Determine the performance of the integrated, "hybrid" recuperator. Conduct both long-term steady state and cyclic testing.

The successful accomplishment of these objectives will answer the following questions:

1. Can a ceramic monolith be successfully integrated into a multi-pass, cross flow recuperator?
2. Can adequate gas sealing be maintained at the metallic/ceramic interface?
3. Can the differential thermal expansions of the materials be dealt with to avoid stress build up on the components?
4. Can greater than 80% effectiveness be obtained in this “hybrid” approach?